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Title: SPE Near Field Velocity Data Corrections and Analysis

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Intended for: Distribution of analysis results to project participants

SPE Near Field Velocity Data Corrections and Analysis

David Steedman/LANL

22 October 2012

Outline

- Gage Corrections
  - General
  - Methodology
- Review of data
  - SPE-1
  - SPE-2 and SPE-3
- Summary
- Recommendations

Gage Corrections

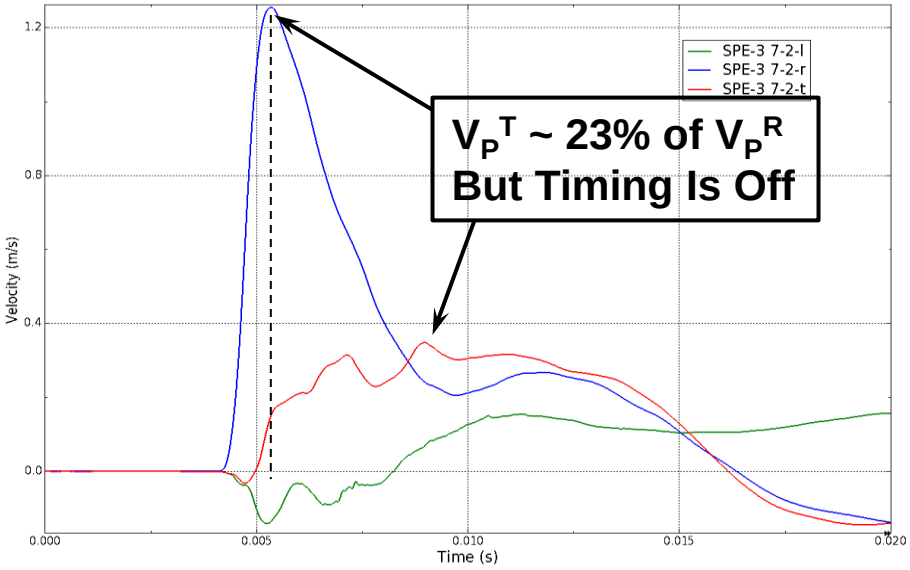
- Gages in holes 1 through 6 are assumed to have rotated
  - The exception is level 3 (*i.e.*, 50-ft depth) gages
  - Jeff Thomsen/ARA determined rotation angle from relative R and T component accelerations
- All gages in holes 7 through 11 were assumed to have not rotated
- All corrected data have been posted to the UNR site
  - mirror1/home/steedmand/speNFcorrections
- For the bulk of this presentation we note that prior analysis has focused on record peak values and arrival times
  - With corrected data we can examine waveforms
  - We review waveforms for level 1 (180-ft) and level 2 (150-ft) depths

Comments on Methodology

- One hypothesis prescribed that joint sets at SPE site "turned" the velocity vector away from a true radial direction
- With recovery of SPE-3 data from newly installed accelerometers the discussion properly focused on shear wave effects (September '12)
- Why revisit this now?
  - Xu email during data correction activity (10/5/12):
    5) The new gages in SPE3 have significant tangential components, causing ~12 degrees deviation of the velocity vector away from the spherical radial direction (a mean of 0.23 for tangential/radial ratio in SPE 3 corresponds to ~12 degrees). The rotation angles calculated should contain this type of error information.
  - This ignores the consensus that the transverse magnitudes are high due to shear wave effects (≠ deviation of vector)

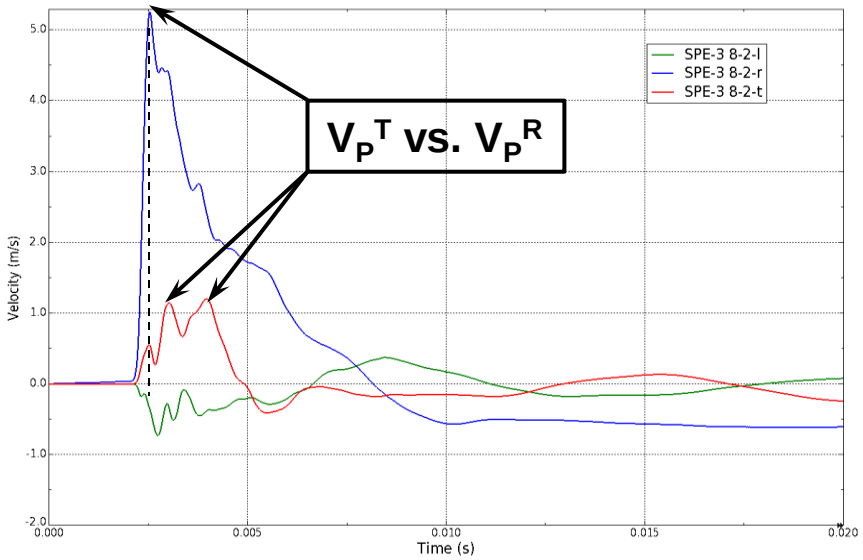
"Turning Vector" vs. Shear Wave Arrivals

- Turning of the vector implies a realignment of the shock front relative to test geometry
  - Off-radial components would be of *similar* shape to radial but with reduced amplitude
  - Specifically, peaks would be coincident

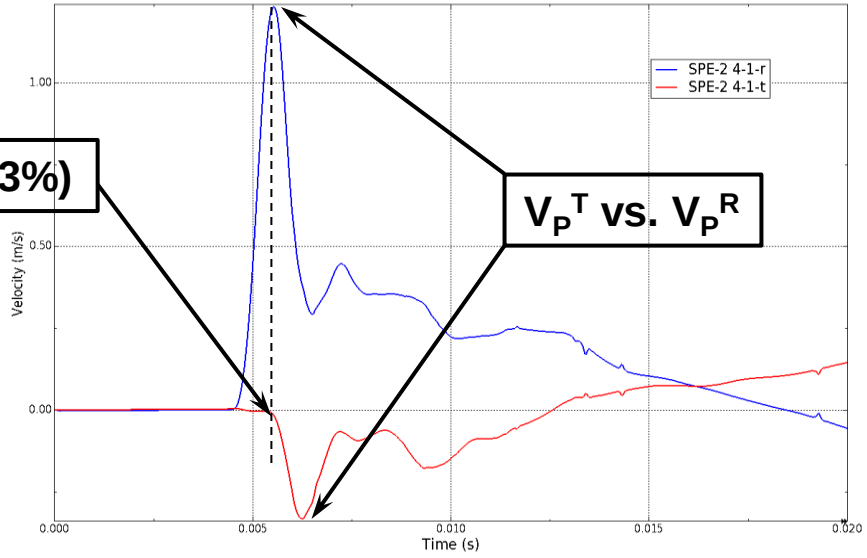


- But in most cases V_P^T lags V_P^R by a significant delay
- Also $V_P^T(t)$ is characteristically different from V_P^R
- History is characteristic of the slower shear wave
  - See data from records that did not require correction such as SPE-3 canister 7-2

Other Examples



SPE-3 8-2



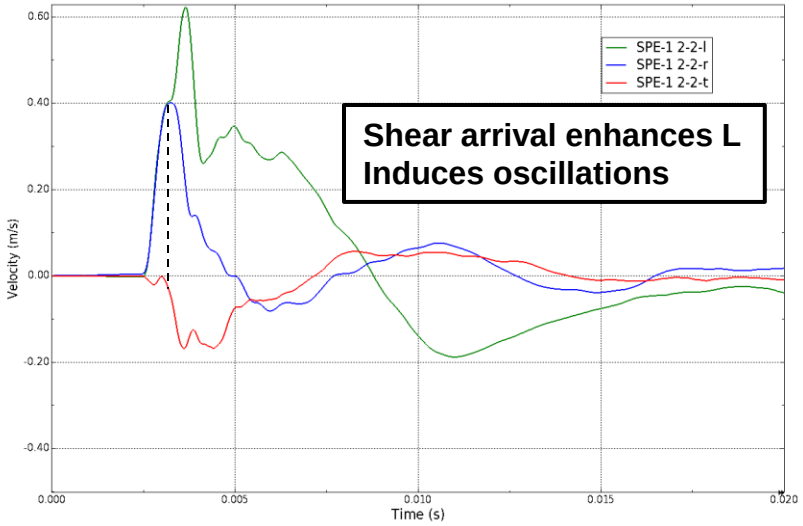
V^T at $t_P^R \cong 0$ (not 23%)

SPE-2 4-1 (Corrected)

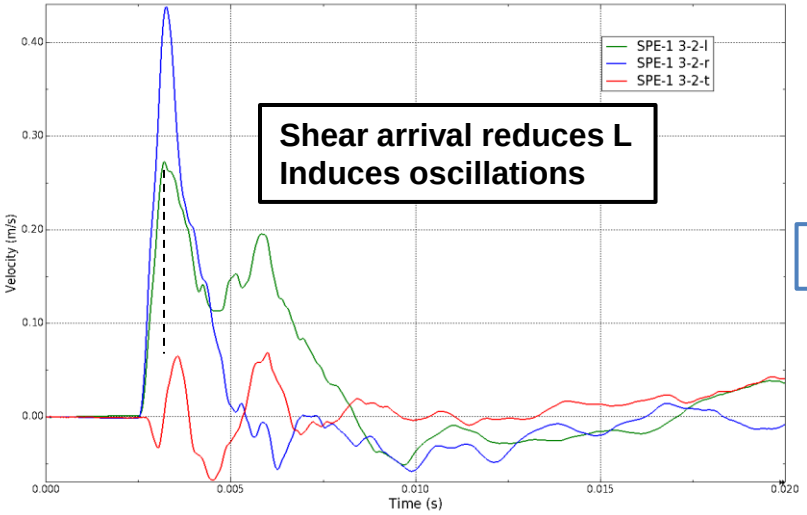
Study Full Data Set

- **Look at SPE-1, then the SPE-2/SPE-3 pair**
  - **Different scaled ranges to gages**
  - **Different yields**
- **In following plots:**
  - **Radial is blue**
  - **Transverse is red**
  - **Longitudinal is green**
  - **All time scales are identical**
  - **Amplitude is self-scaled**

SPE-1 Data– 10-m Range

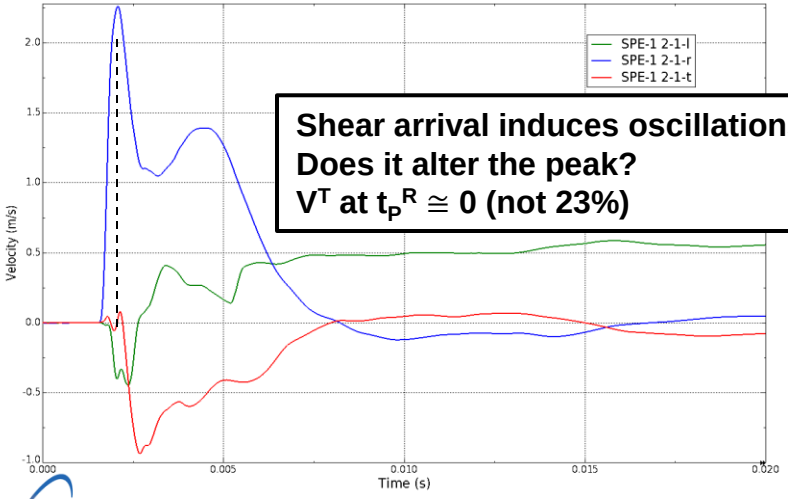


Shear arrival enhances L
Induces oscillations



Shear arrival reduces L
Induces oscillations

150-ft Depth



Shear arrival induces oscillations in R
Does it alter the peak?
V^T at $t_P^R \cong 0$ (not 23%)

Insufficient Data to Estimate Rotation in 3-1

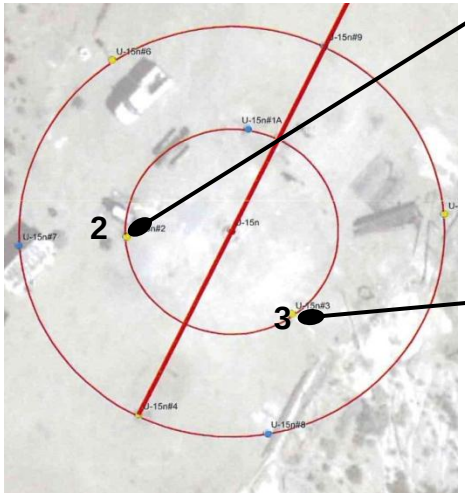
180-ft Depth

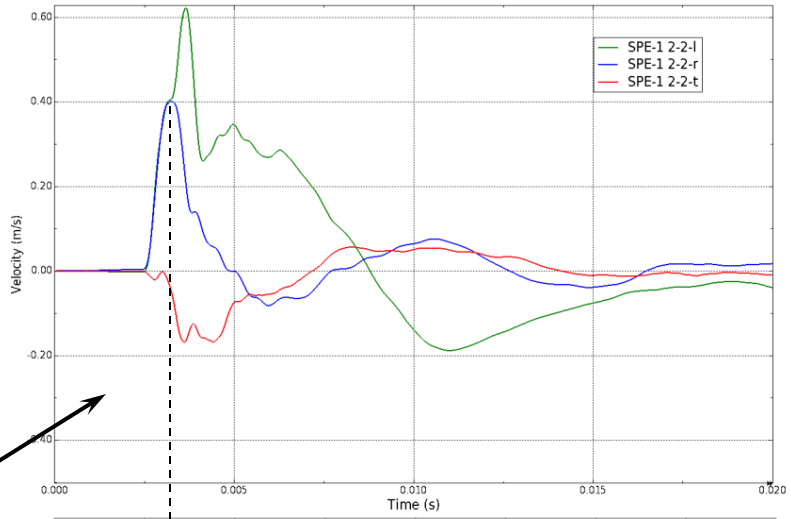
Hole 2

Hole 3

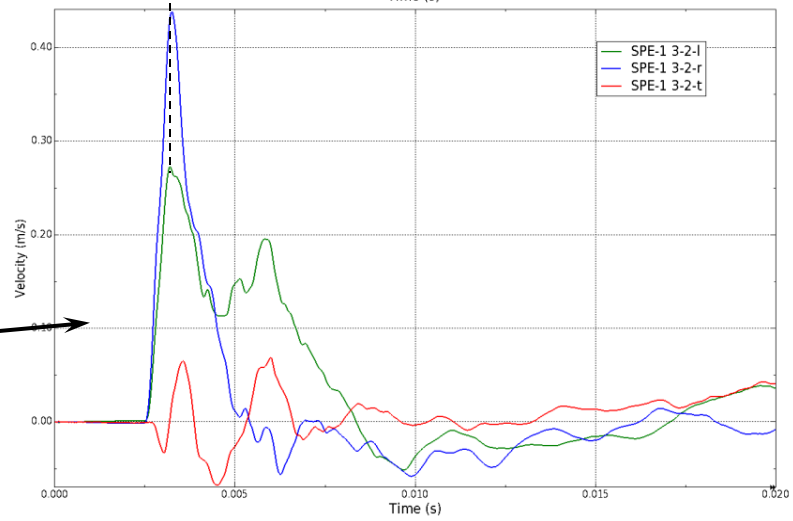
SPE-1 Data– 10-m Range, 150-ft depth (45º from source)

- **R-component and L-component should be equal**
  - **Shear arrivals alter L-component at both locations**
- **Shear arrivals at two different azimuths are coincident in time**
  - **Suggests a common source**
  - ***i.e.*, the explosive source vs. random joints**



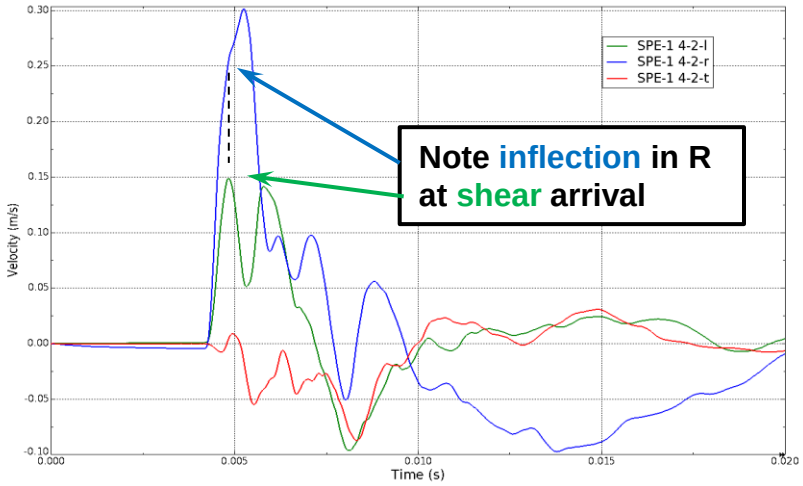


Hole 2

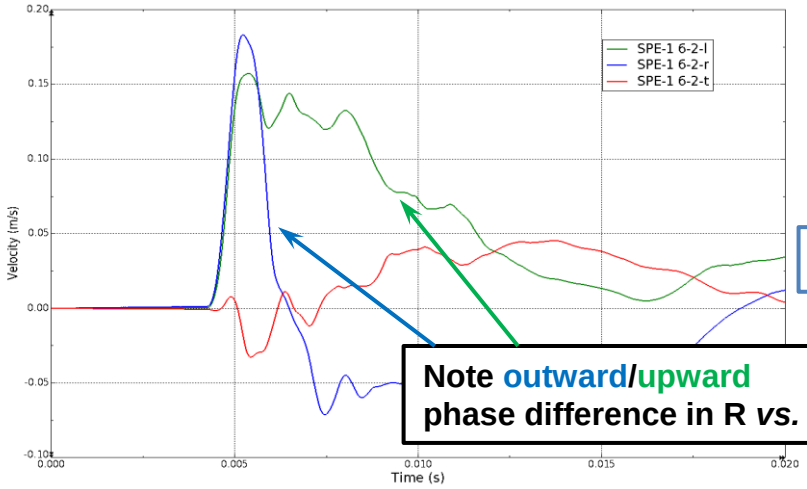


Hole 3

SPE-1 Data– 20-m Range

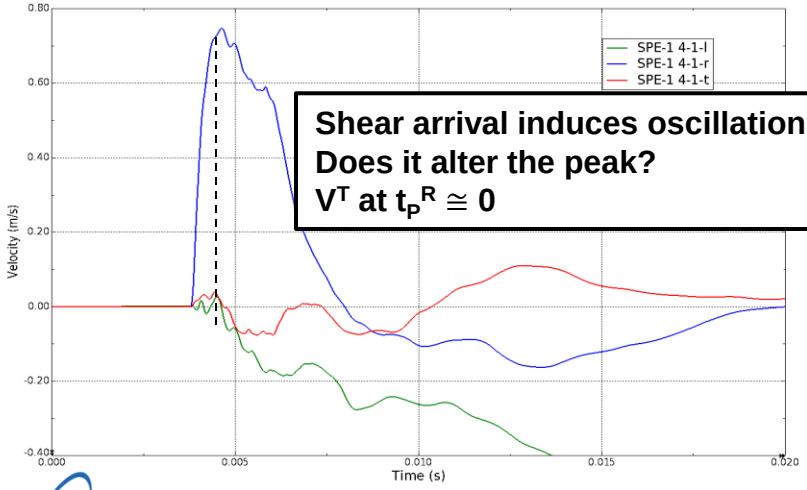


Note **inflection** in R at **shear** arrival

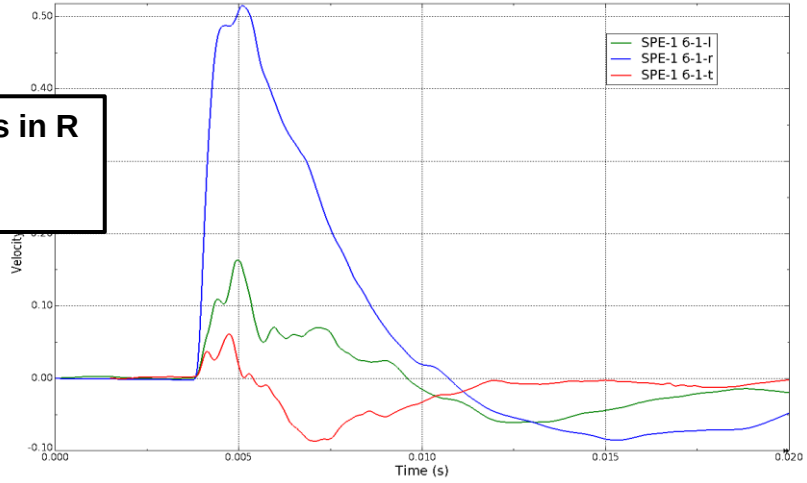


Note **outward**/**upward** phase difference in R *vs.* L

150-ft Depth



Shear arrival induces oscillations in R
Does it alter the peak?
V^T at $t_P^R \cong 0$



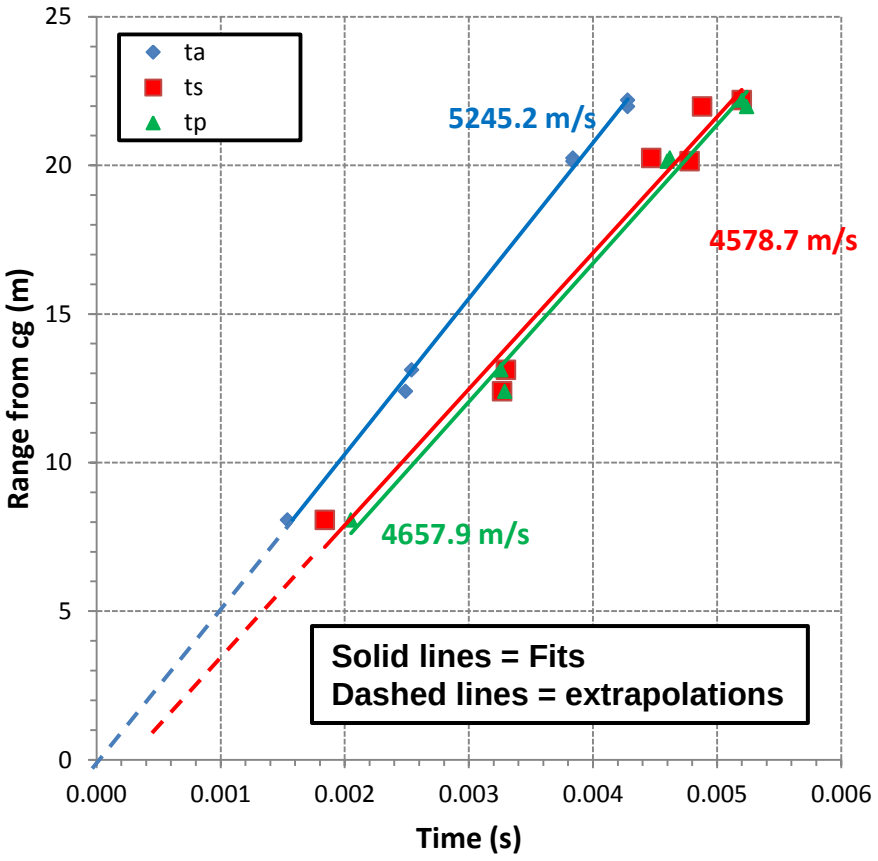
180-ft Depth

Hole 4

Hole 6

SPE-1 Arrival Times

- **Shear speed about equal to loading speed**
  - **Times to peak and peak amplitudes are likely obscured by shear wave**
- **Tight trend in shear arrivals suggest a common source**

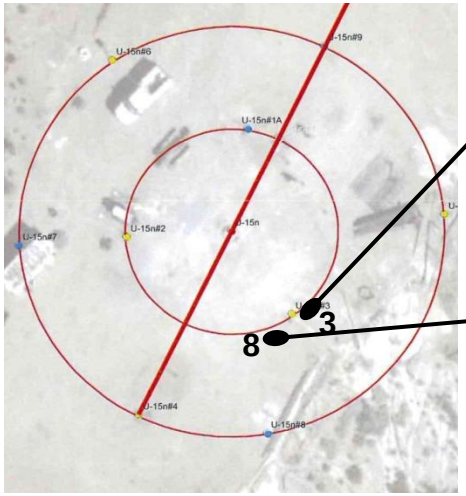


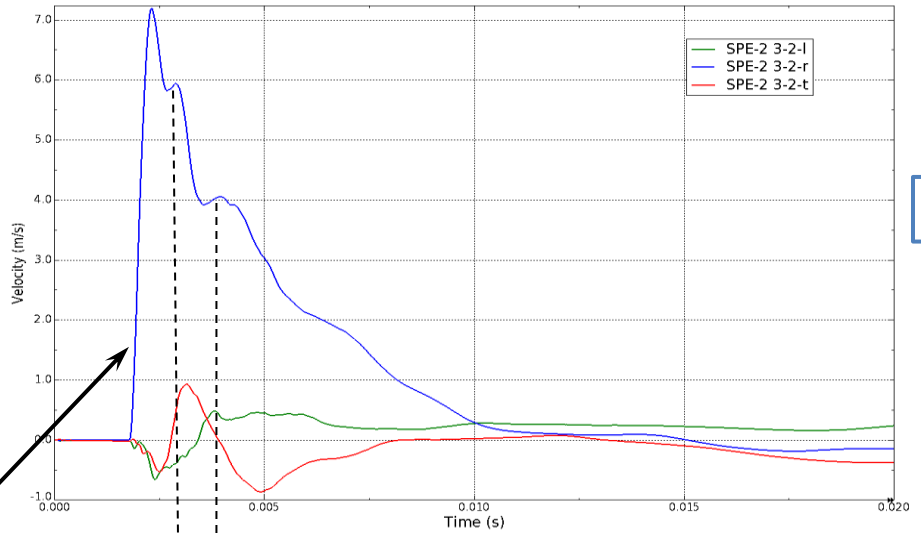
SPE-2 and SPE-3 Data Repeatability

- **Several methods indicate that SPE-2 created a damaged medium for SPE-3**
  - **Near field late arrivals and lower amplitude**
  - **Cross-hole survey**
  - **Infrasound**
  - **Slant hole fractured core**
- **But gage-by-gage SPE-3 data are remarkably similar to SPE-2 data**
  - **Most notable for R-components**
  - **But also some T- and L- components**

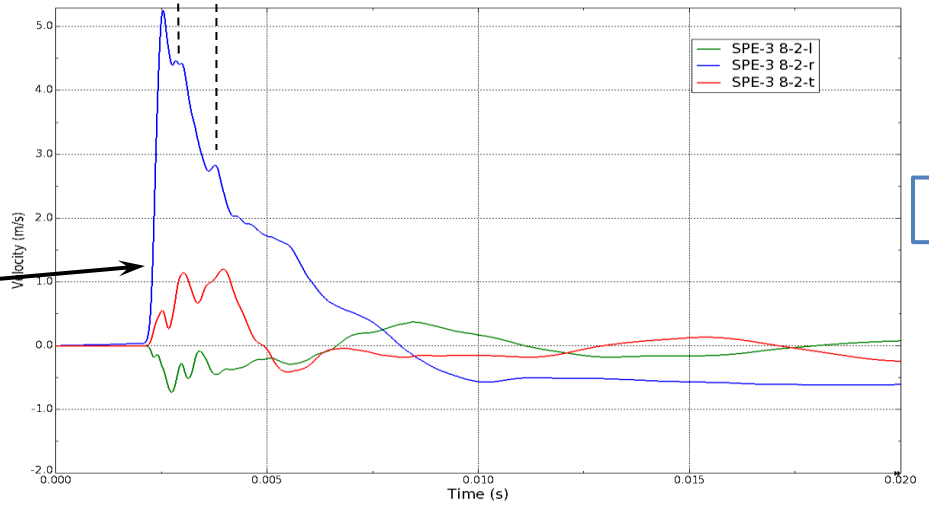
SPE-2/SPE-3– 10-m Range, at Shot Depth

- **No 3-2-R in SPE-3, but nearby 8-2-R in SPE-3 is very similar to 3-2-R in SPE-2**



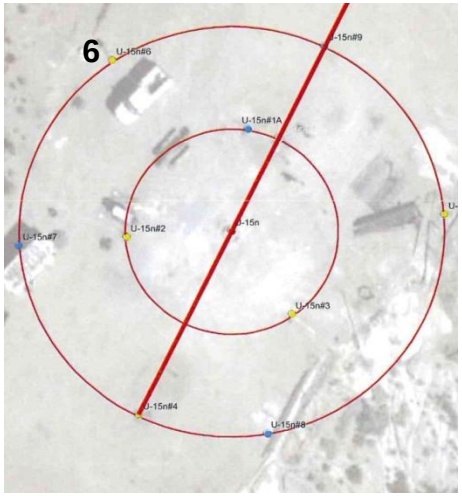


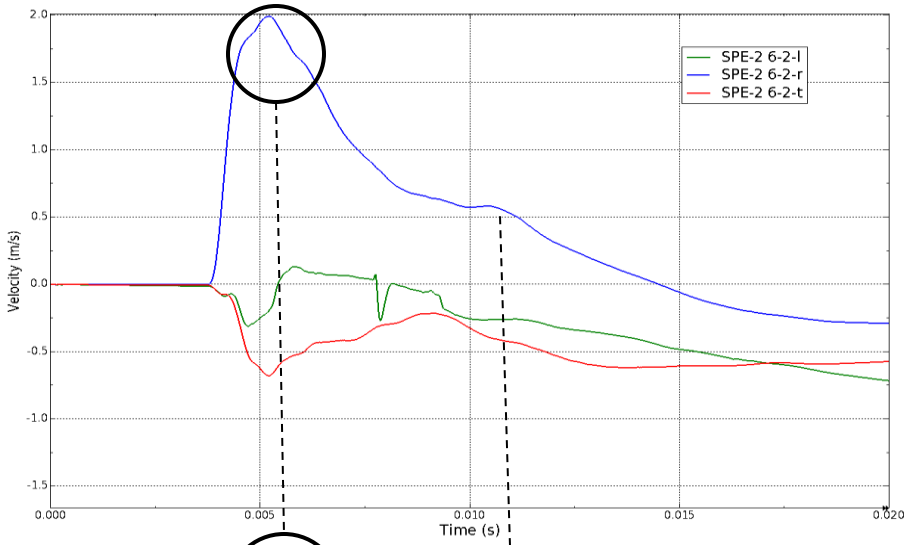
SPE-2



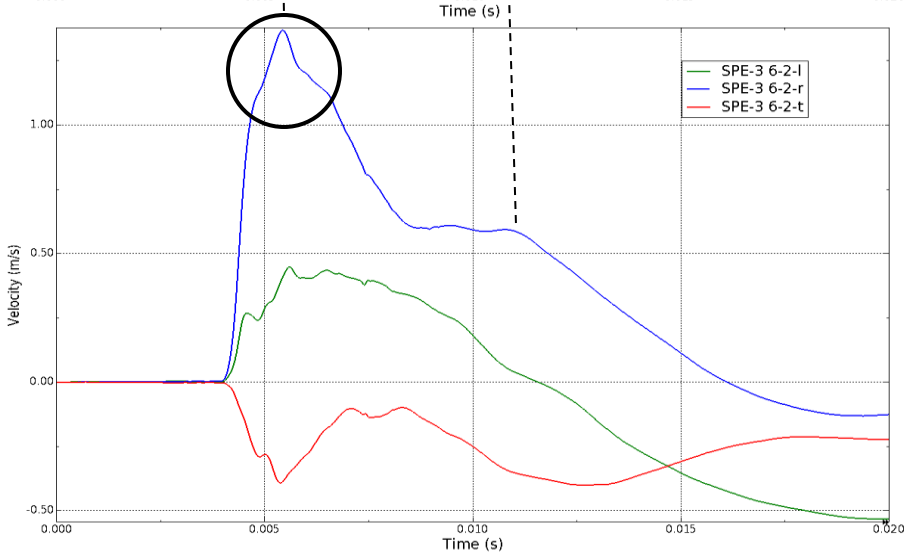
SPE-3

SPE-2/SPE-3– 20-m Range, Shot Depth



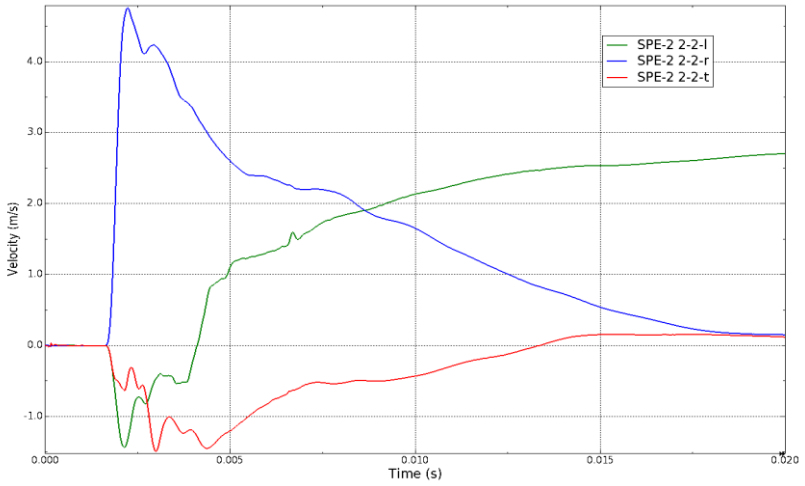


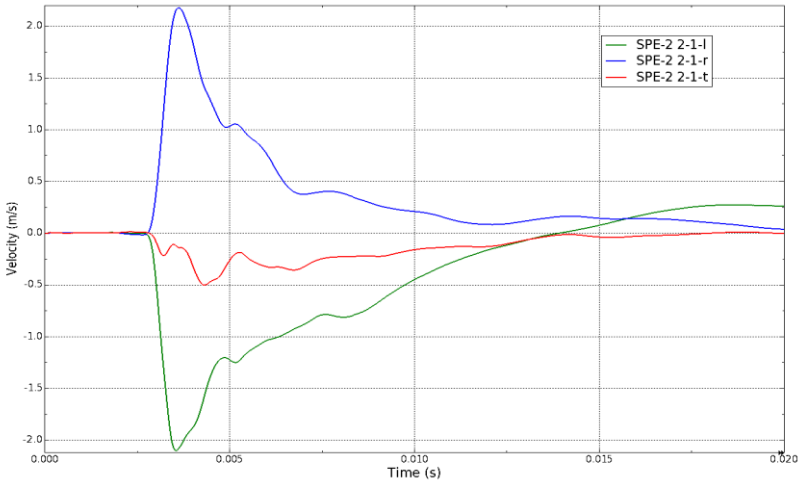
SPE-2



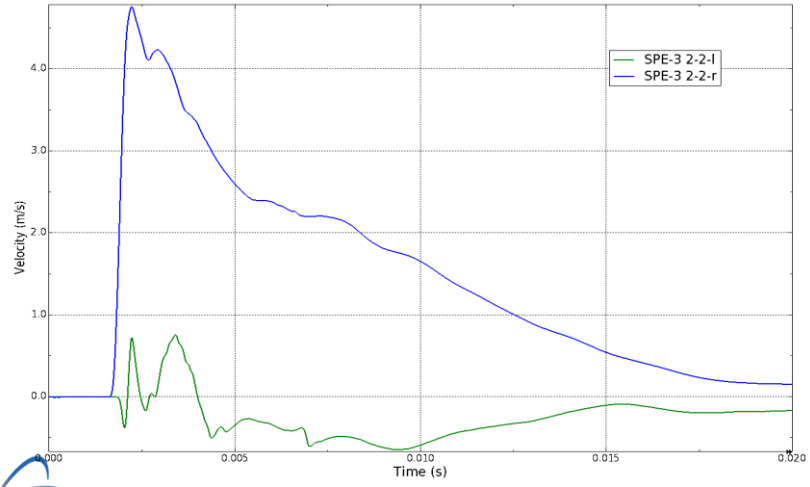
SPE-3

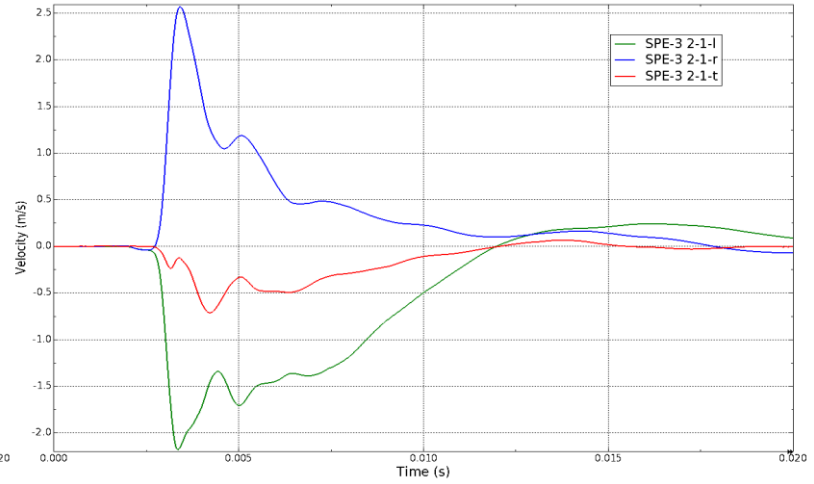
SPE-2/SPE-3– Hole 2





SPE-2



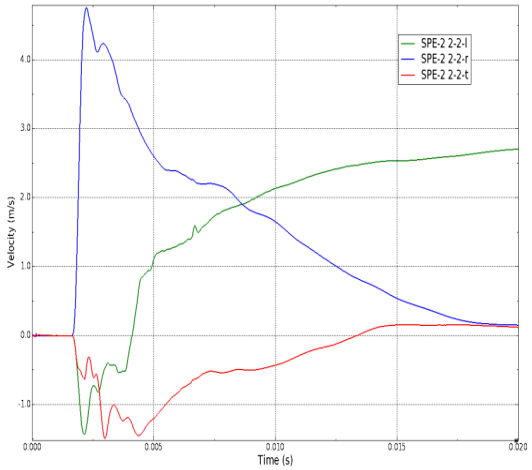


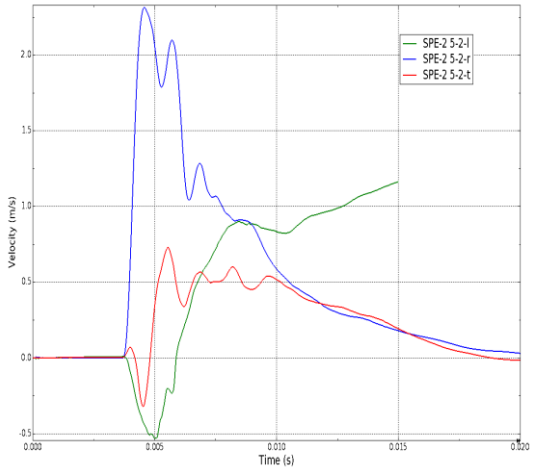
SPE-3

150-ft Depth

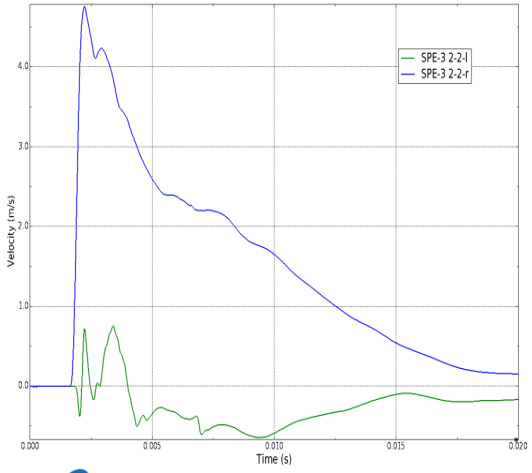
180-ft Depth

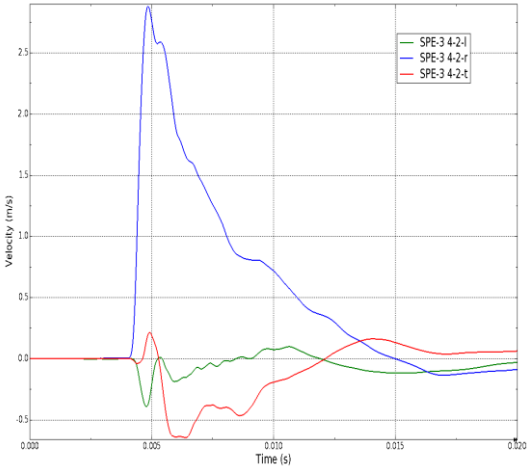
SPE-2/SPE-3– Three-component Repeatability

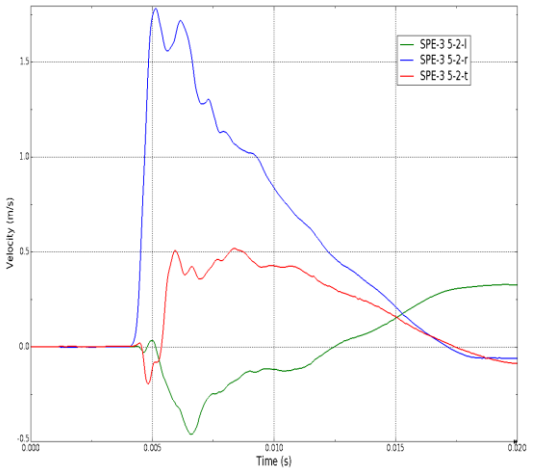




SPE-2





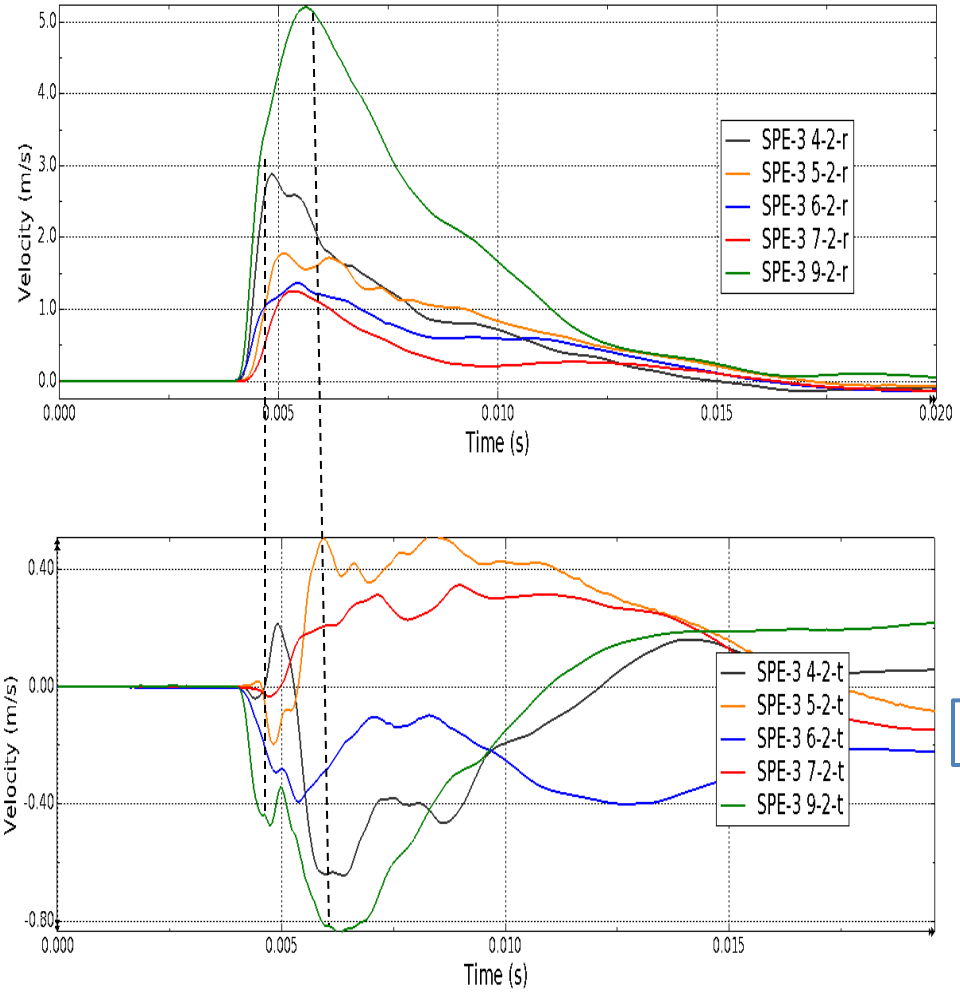


SPE-3

Hole 2 **Hole 4** **Hole 5**

SPE-3– Revisit Can 9-2

- 9-2-R anomalously high
- Review all SPE-3 at 20-m range and shot depth
- Strong 9-2-T shear coincides with 9-2-R inflection
  - Amplitude increases by 60% after inflection
  - That is of the order increase that was experienced by SPE-1 can 2-2-L after shear arrival

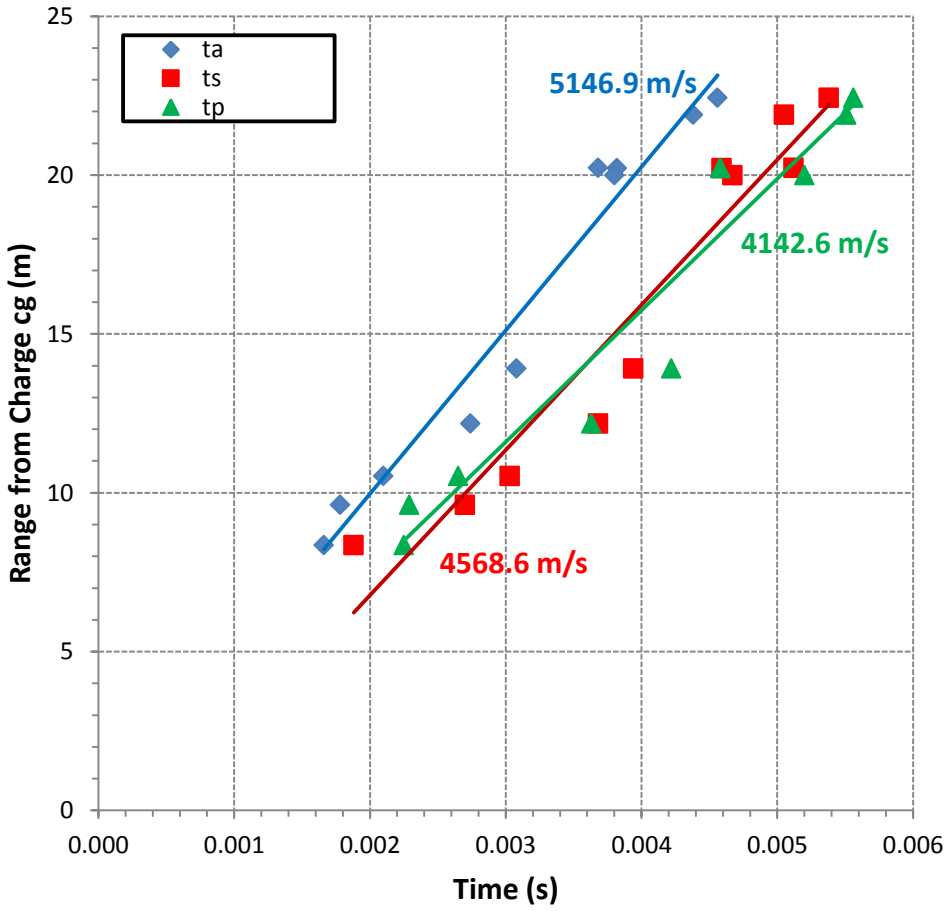


Radial

Transverse

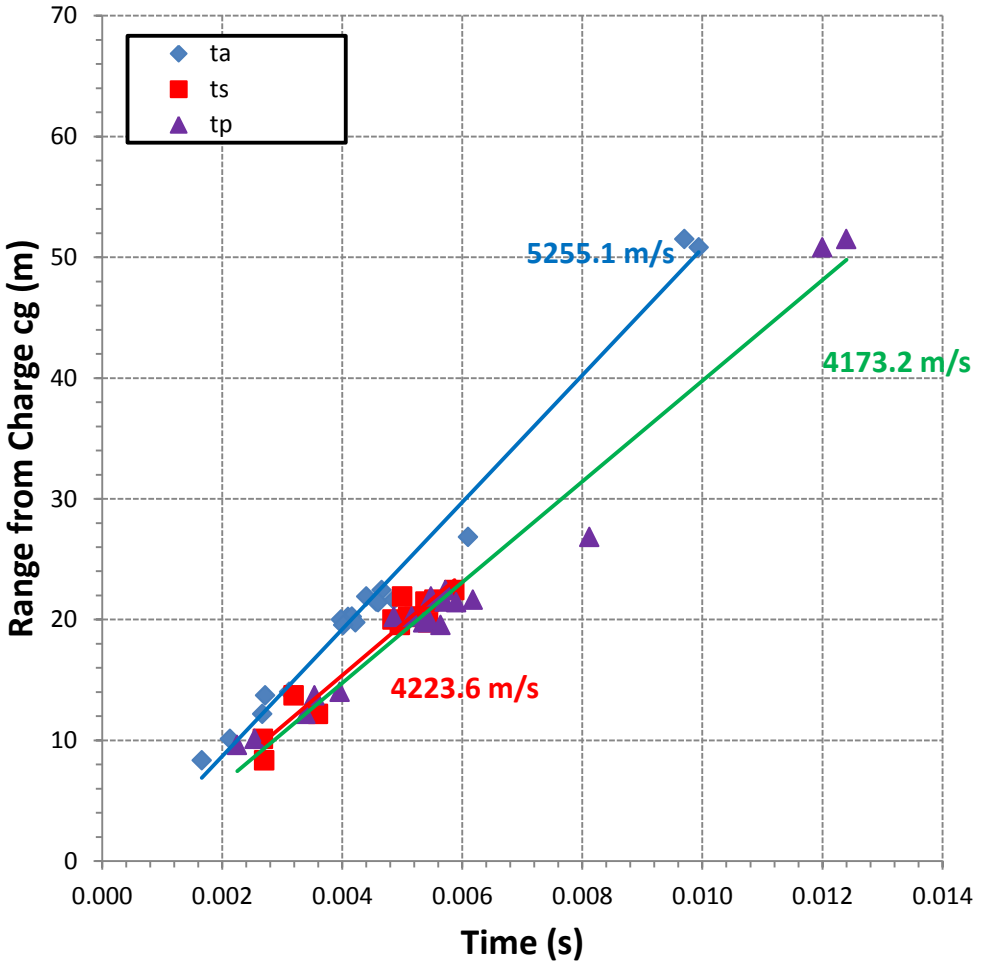
SPE-2 Arrival Times

- **Similar characteristics as for SPE-1; i.e.,**
  - **Shear arrivals "interfere" with peaks**
  - **Trend in shear arrivals suggests a common source**



SPE-3 Arrival Times

- **Similar characteristics as for SPE-1 and SPE-2**



SPE-2/SPE-3– Summary

- **SPE-3 histories resemble SPE-2, even down to small perturbations**
- **Similarities/Differences**
  - **Explosive sources for these events were nearly identical**
  - **The rock medium for SPE-3 was damaged by SPE-2**
- **It follows that the consistent waveforms reflect consistent source characteristics**

Summary

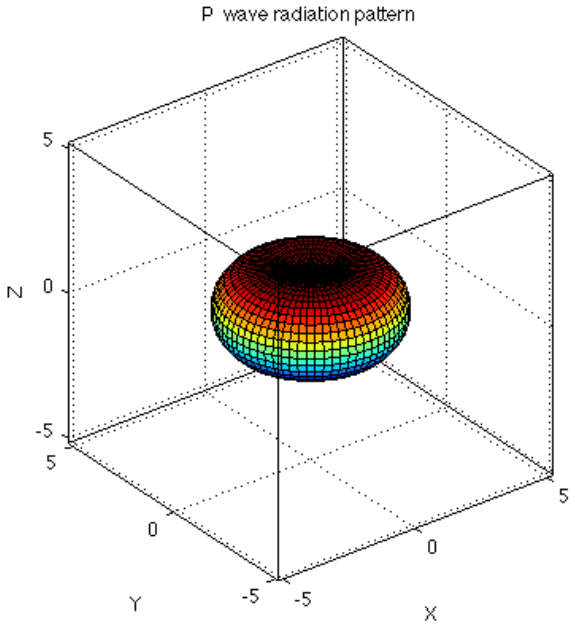
- There appear to be significant shear waves in the SPE ground shock environment
- Arrival times suggest a point source (explosive) rather than a distributed source (rock joints)
- Character of waveforms is similar when considering like range and depth across differing azimuths
- Character of waveforms is repeatable across experiments with repeated source yield and location

Discussion

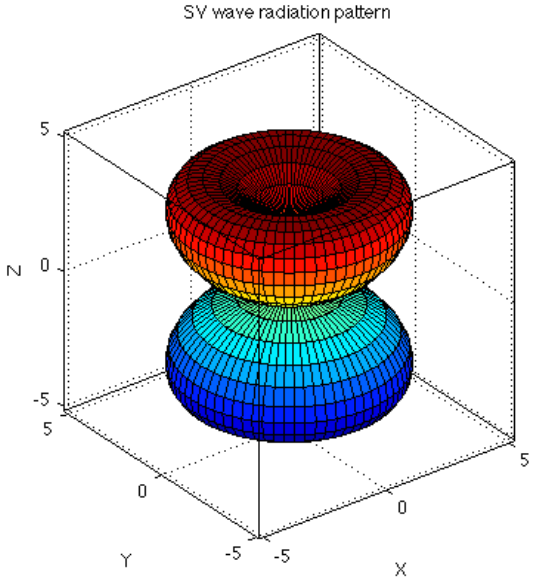
- **Would a spherical source cause similar shear waves?**
- **If so, do we want to study cylindrical sources or spherical sources?**

Theoretical Radiation from a Cylindrical Source

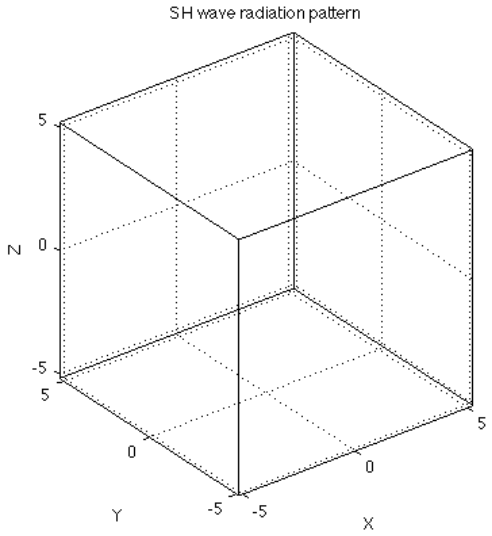
- From a moment tensor for cylindrical charge
  - L/D = 4
  - Significant SV radiation predicted



P-Radiation



SV-Radiation



SH-Radiation

Recommendation

- **If we are interested in cylindrical sources**
  - **Proceed as planned**
- **If we are interested in spherical sources**
  - **Numerical simulations are required to compare environments created by cylindrical sources to those from spherical sources**
  - **Design SPE-4 as a spherical source**
  - **If study/SPE-4 show that there is no difference → Proceed as planned**
  - **If study/SPE-4 show that there is a difference → Reconsider future event designs**

Addendum

- **Discussion: how are different sources of non-radial motion (turning shock vector vs. shear arrivals) manifest in the recorded data?**

Comments on Phenomenology

- It has been hypothesized that joint sets at SPE site turn the velocity vector away from a true radial direction
  - This was based on observing relatively large transverse motions
  - But for SPE-1 and SPE-2, often the transverse amplitude was *greater* than the radial; by more than factor of 5 in some cases
    - No credible explanation provides for this large a variation
  - Moreover, the site joints are 3-D and there is no evidence suggesting the joints have similarly affected the longitudinal (*i.e.*, vertical) measurements
- SPE-3 data from newly installed accelerometers do not display these excessive transverse amplitudes
- Why revisit this now?
  - Xu email during data correction activity (10/5/12):

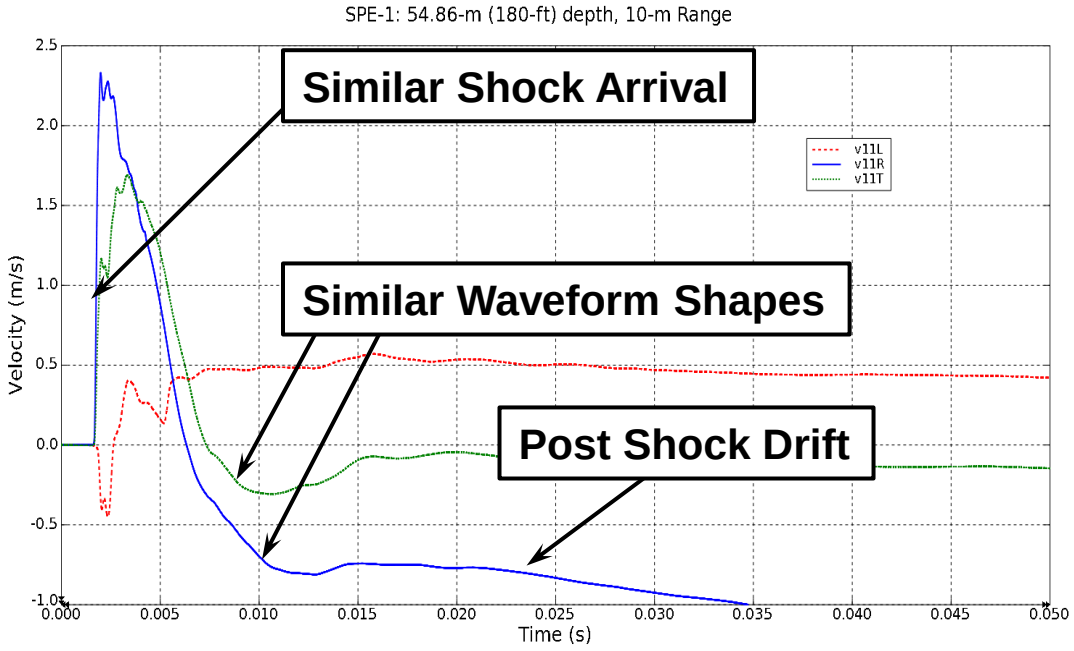
    5) The new gages in SPE3 have significant tangential components, causing ~12 degrees deviation of the velocity vector away from the spherical radial direction (a mean of 0.23 for tangential/radial ratio in SPE 3 corresponds to ~12 degrees). The rotation angles calculated should contain this type of error information.

“Turning Vector” vs. Shear Wave Arrivals

- Turning of the vector implies a realignment of the shock front relative to test geometry
- If this were true:
  - Off-radial components would be of *similar* shape to radial but with reduced amplitude
  - Peaks would be coincident, or nearly coincident, and waveforms would be similar (duration, shape, *etc.*)
- This result would be indistinguishable from a rotated gage package except for one point:
  - The site joint systems are 3-D, consequently, the phenomenon affecting the transverse motion should occur to a similar degree on the longitudinal measurements
  - Conversely, rotation of the gage package would have no effect on a longitudinal history

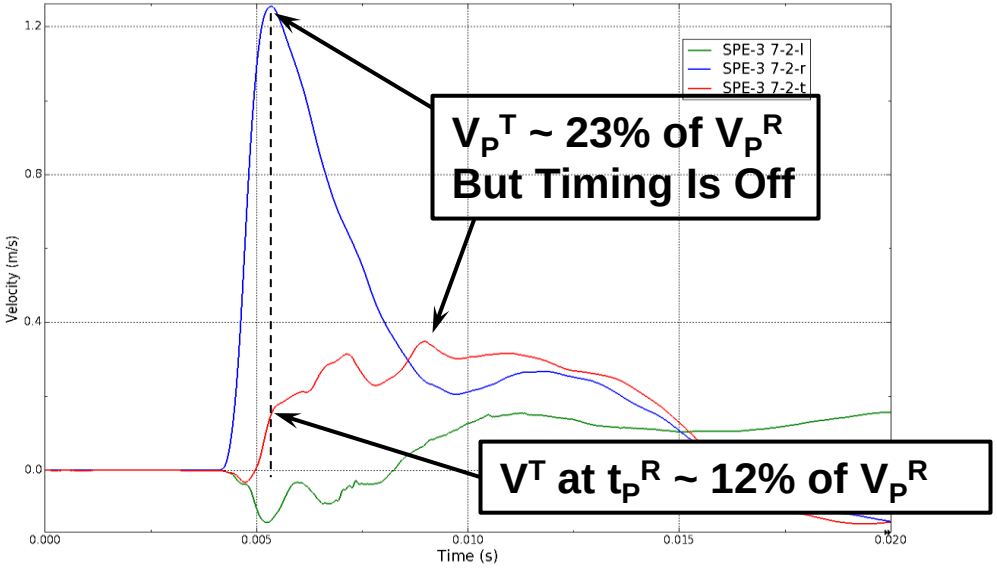
“Turning Vector” vs. Shear Wave Arrivals (cont.)

- **The uncorrected histories from SPE-1 can 1-1 provide an example**
  - **The radial and transverse waveforms are nearly identical except for lower transverse peak and a post-shock negative drift in the radial**
  - **But the longitudinal history is radically different, and has a peak about 20% of the radial peak**
  - **This combination of effects suggests that the high transverse is due to a rotated gage, not a rotated shock front**



“Turning Vector” vs. Shear Wave Arrivals

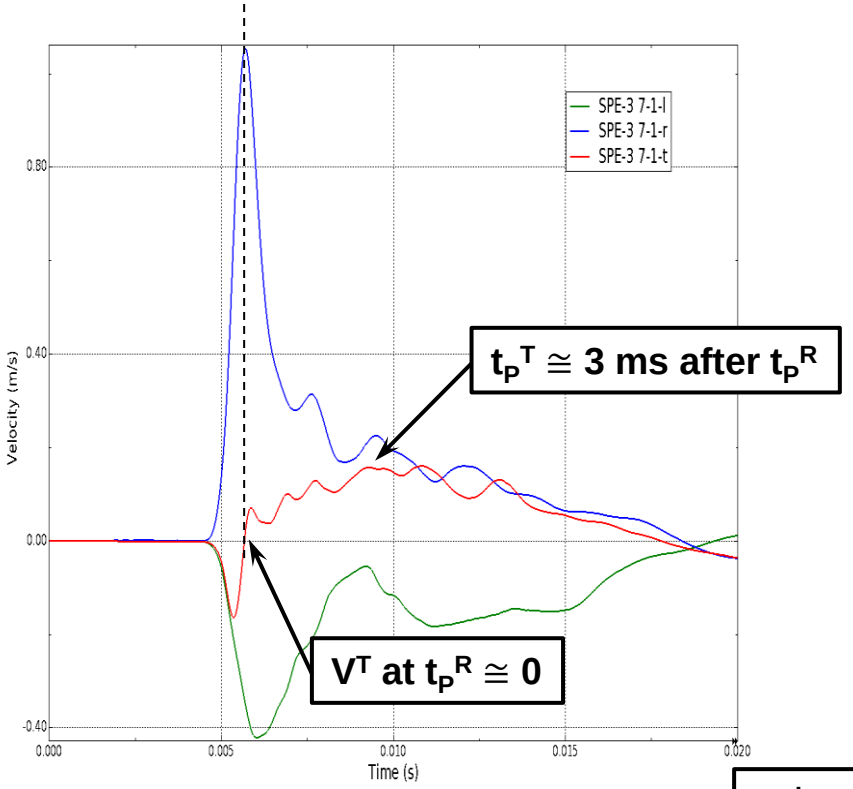
- We can contrast this with a can where there is high confidence that it did not rotate
- The peak transverse velocity (V_P^T) lags the peak radial velocity (V_P^R) by a significant delay
- The transverse history ($V_P^T(t)$) is characteristically different from the radial history (V_P^R)
- The longitudinal history ($V_P^L(t)$) is also characteristically different from the radial history (V_P^R) with a small peak



Review all Gages in Holes 7 – 11 (Except for Slant Hole 10)

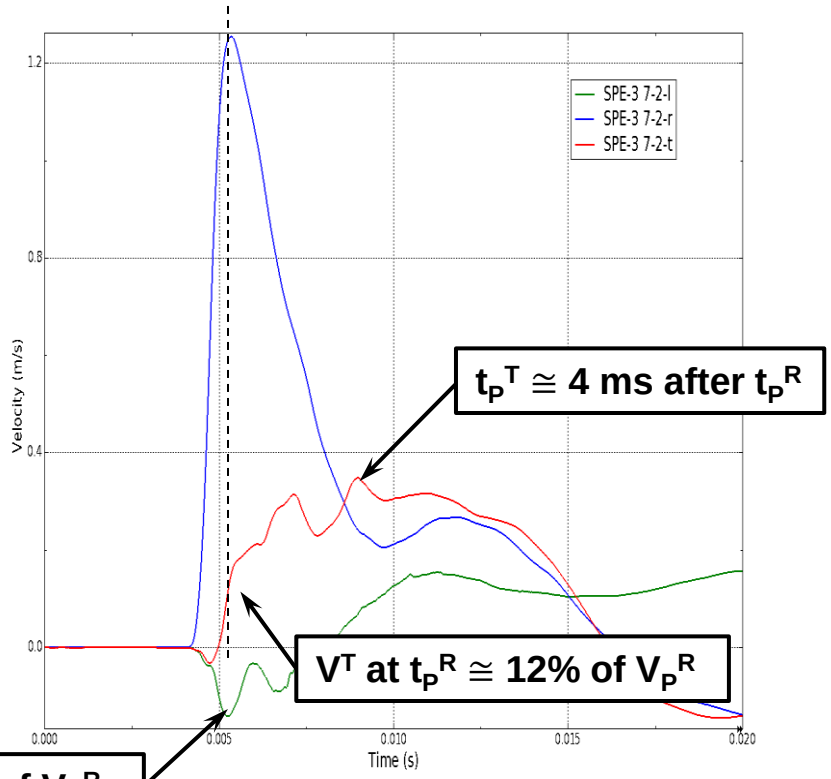
- To study this further, review SPE-3 data for all data that did not require rotation
  - Transverse peak value relative to radial peak
  - Time of transverse peak relative to radial peak
  - Value of transverse velocity at time of radial peak
  - Review longitudinal response as well
    - In particular, review longitudinal histories at the shot depth (level 2)
- Focus on level 1 and level 2 gages
  - Ground surface, weathered-to-intact interface and water table complicate the level 3 response
  - We will examine levels 1 through 4 for hole 9

Hole 7



$t_P^T \cong$ 3 ms after t_P^R

V^T at $t_P^R \cong 0$



$t_P^T \cong$ 4 ms after t_P^R

V^T at $t_P^R \cong$ 12% of V_P^R

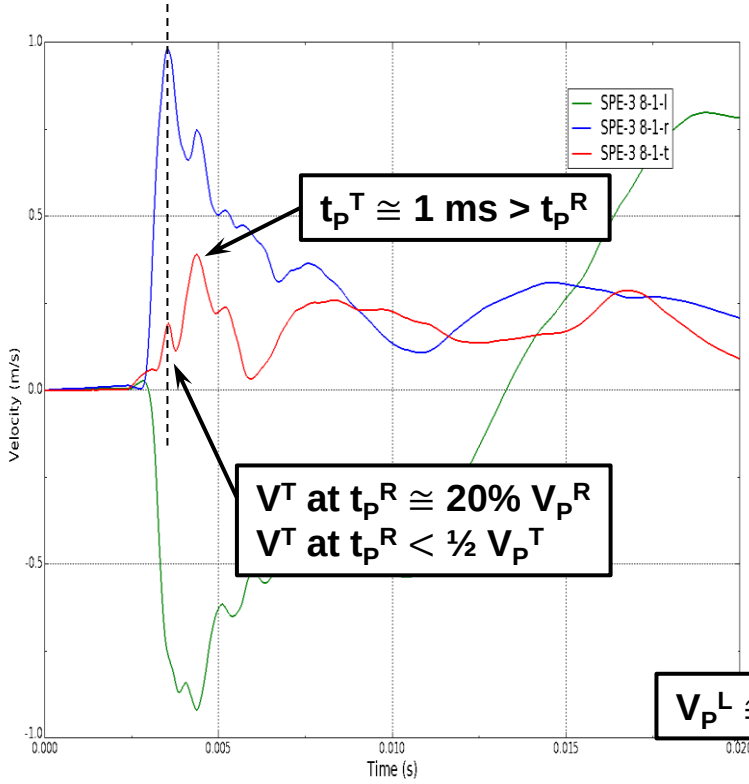
$V_P^L \cong$ 12% of V_P^R

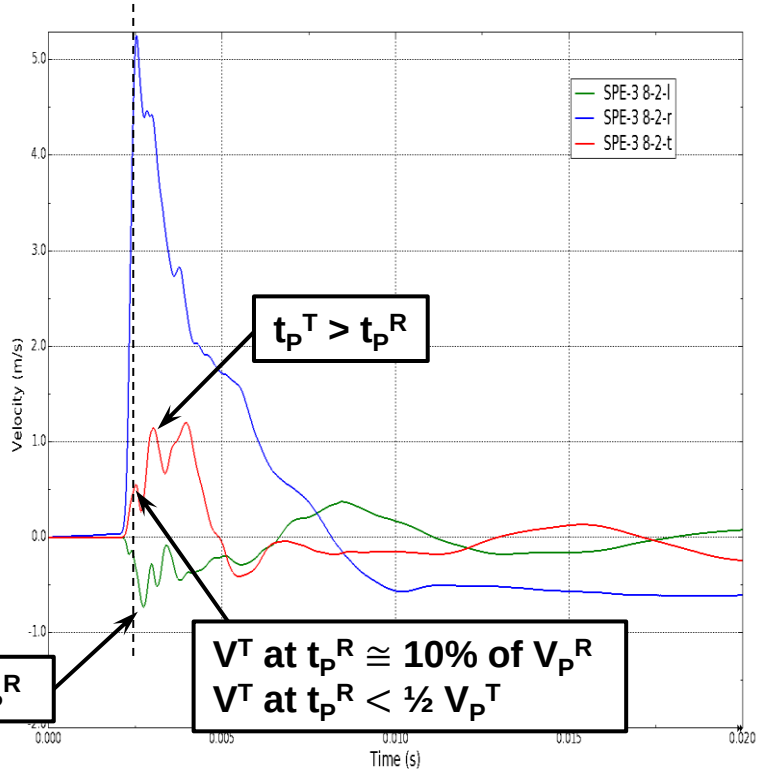
There is no characteristic similarity between radial and transverse; although after 12 ms the respective curves are nearly the same

7-1

7-2

Hole 8





$V_P^L \cong 14\%$ of V_P^R

There is no characteristic similarity between radial and transverse

Transverse has ½ the first phase duration as radial

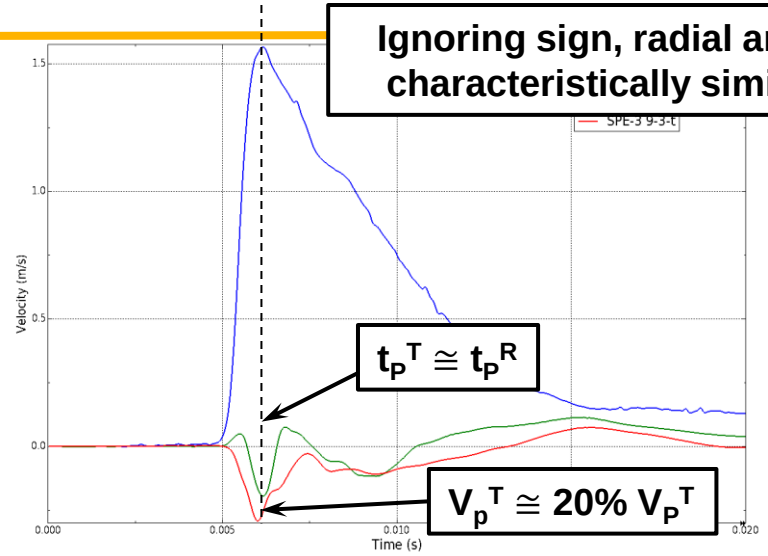
8-1

8-2

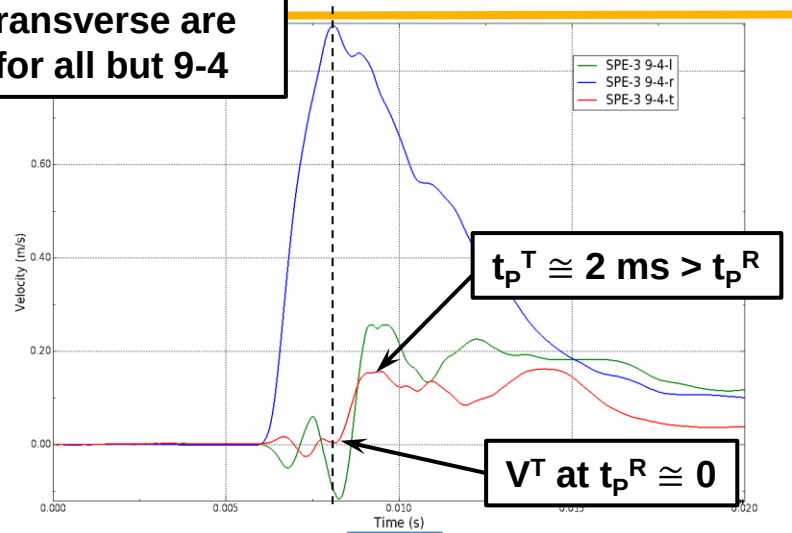
Hole 9

Earth & Environmental Sciences

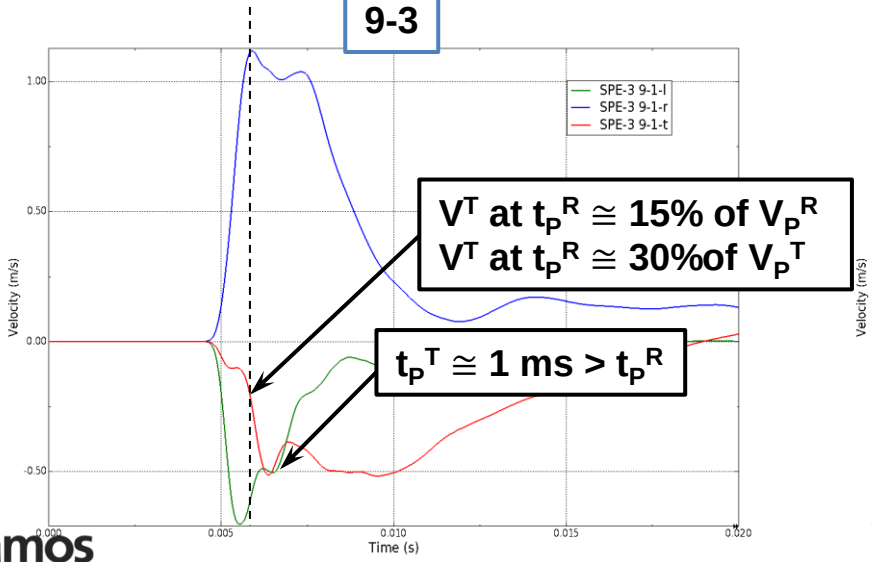
Ignoring sign, radial and transverse are characteristically similar for all but 9-4



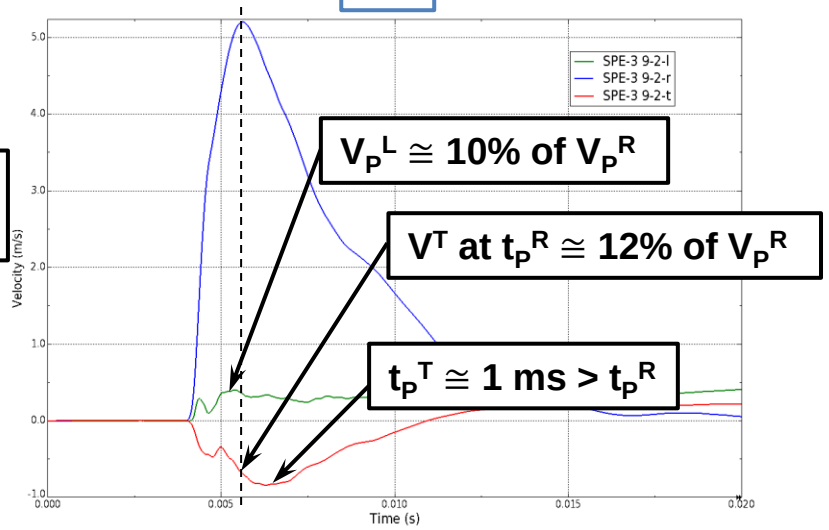
9-3



9-4



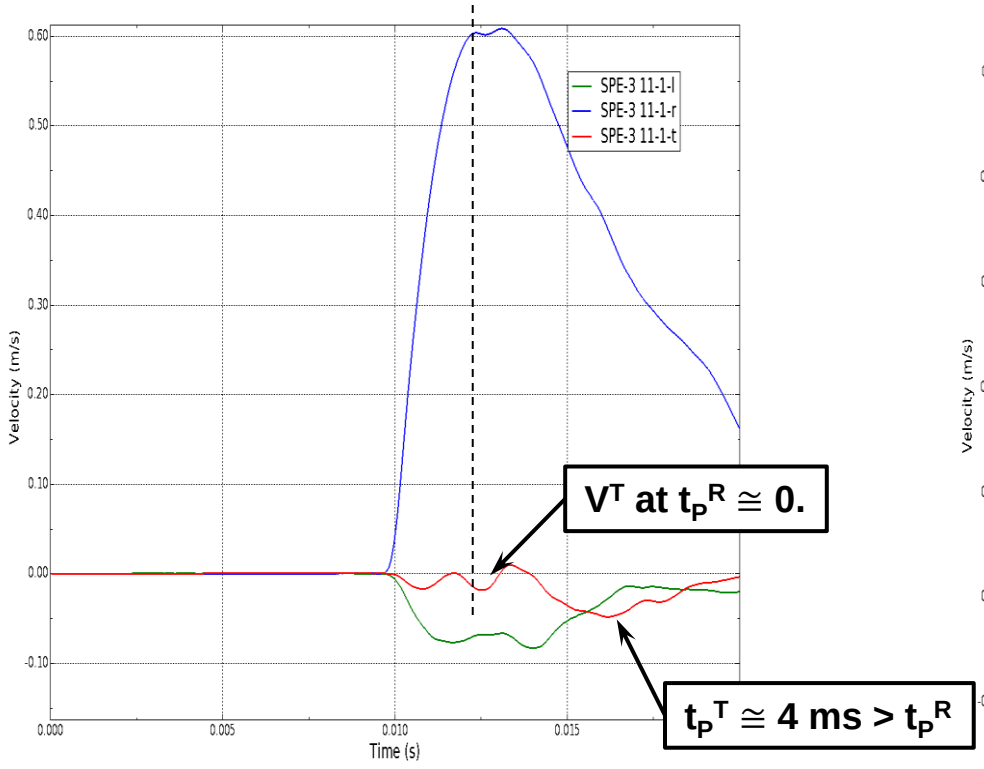
9-1

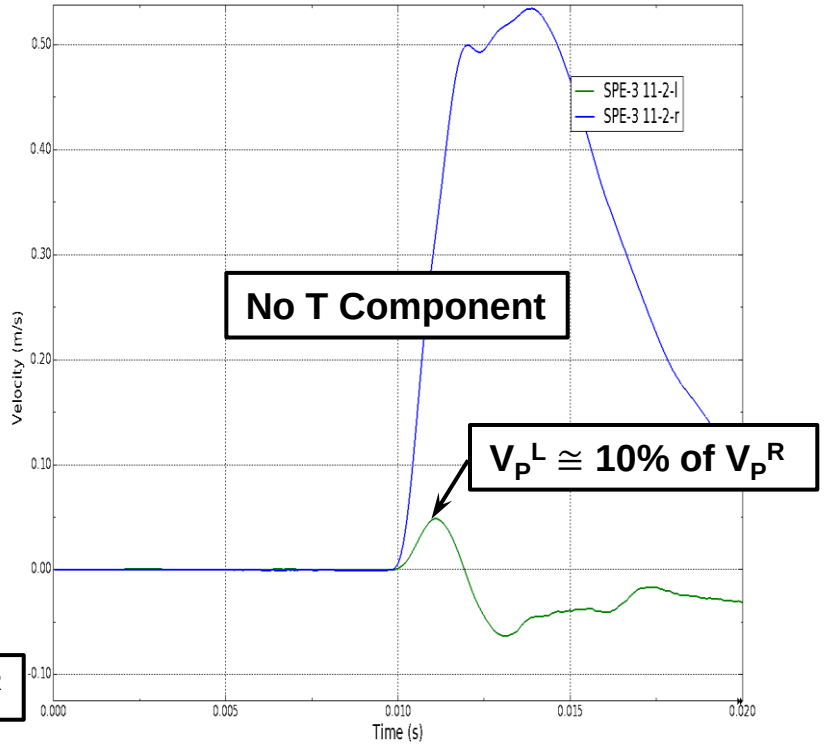


9-2

Los Alamos NATIONAL LABORATORY EST. 1943

Hole 11





There is no similarity between radial and transverse

11-1

11-2

Resolved Horizontals

- Take the peak radial velocity
- Use the Transverse velocity value at the time of the peak radial
- Compute the peak of the resolved vector in the horizontal plane (i.e., neglect longitudinal contribution)
- The transverse component provides an insignificant contribution to the resolved horizontal velocity
- The vector is not deviating from the geometric radial

Can	Peak Radial (m/s)	Transverse at Time of Peak Radial (m/s)	Resolved peak (m/s)
7-1	1.054	0.0271	1.054
7-2	1.255	0.157	1.265
8-1	0.98	0.189	0.998
8-2	5.249	0.537	5.276
9-1	1.119	0.225	1.141
9-2	5.205	0.691	5.251
9-3	1.565	0.259	1.586
9-4	0.898	0.005	0.898
11-1	0.604	0.017	0.604

Hole 7-11 Observations

- **Hole 7**
  - **Level 1**
    - **The transverse peak lags the radial peak by a considerable time**
    - **The transverse amplitude at the time of radial peak is zero**
    - **The general character of the radial and transverse histories are quite dissimilar, although they nearly overlay after 12 ms time**
  - **Level 2**
    - **The transverse peaks lags the radial peak by a considerable time**
    - **The transverse amplitude at the time of radial peak is about 12% of the radial peak**
    - **The transverse amplitude at the time of the radial peak is about 1/3 of the transverse peak**
    - **The general character of the radial and transverse histories are quite dissimilar, although they nearly overlay after 12 ms time**

Hole 7-11 Observations (cont.)

- **Hole 8**
  - **Level 1**
    - **The transverse peak, while about ½ the radial peak amplitude, lags the radial peak by about 1 ms**
    - **The transverse amplitude at the time of radial peak is about 10% of the radial peak, and is less than ½ the value of its own peak**
    - **The general character of the radial and transverse histories are quite dissimilar**
  - **Level 2**
    - **The transverse peak, while about 20% of the radial peak amplitude, lags the radial peak by about 1 ms**
    - **The transverse amplitude at the time of radial peak is about 10% of the radial peak, and is less than ½ the value of its own peak**
    - **The general character of the radial and transverse histories are quite dissimilar; with the first phase of the transverse being about one half the duration of the radial outward phase**

Hole 7-11 Observations (cont.)

- **Hole 9**
  - **Level 1**
    - **The transverse peak, while about 30% of the radial peak amplitude, lags the radial peak by about 1 ms**
    - **The transverse amplitude at the time of radial peak is about 15% of the radial peak, and is about 30% of the value of its own peak**
    - **The general character of the radial and transverse histories are not similar**
  - **Level 2**
    - **The transverse peak, while about 17% of the radial peak amplitude, lags the radial peak by about 1 ms**
    - **The transverse amplitude at the time of radial peak is about 12% of the radial peak**
    - **The general character of the radial and transverse histories are similar**

Hole 7-11 Observations (cont.)

- **Hole 9 (cont.)**
  - **Level 3**
    - **Except for sign, the transverse history is characteristically similar to the radial history**
    - **The radial and the transverse peaks are nearly simultaneous**
    - **The transverse peak amplitude is about 20% of the radial peak amplitude**
  - **Level 4**
    - **The transverse peak, while about 20% of the radial peak amplitude, lags the radial peak by about 2 ms**
    - **The transverse amplitude at the time of radial peak is 0.**
    - **The general character of the radial and transverse histories are quite dissimilar**

Hole 7-11 Observations (cont.)

- **Hole 11**
  - **Level 1**
    - **The transverse peak lags the radial peak by about 4 ms**
    - **The transverse amplitude at the time of radial peak is nearly 0.**
    - **The transverse peak amplitude is 8% of the radial peak amplitude**
    - **The general character of the radial and transverse histories are quite dissimilar**

Hole 7-11 Observations (concl.)

- **For all canisters**
  - **Peaks**
    - **The transverse peak generally lags the radial peak by several ms**
    - **The amplitude of the transverse waveform at the time of radial peak is generally less than 10% of the radial peak (close to 0. in some cases)**
    - **The longitudinal peaks are generally less than 10% of the radial peaks**
  - **Character**
    - **The character of the transverse waveform is generally considerably different from the character of the radial waveform**
    - **In nearly all cases the character of the longitudinal waveform is considerably different than the character of the radial waveform**
- **These characteristics all argue for late time phenomena that are not concurrent with the main shock**
  - **The “high” (i.e., non-zero) transverse measurements are not indicative of a turning shock vector**